Jet Propulsion Laboratory
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New Approaches for Primary Battery Power System Design

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Agenda

- Background & Relevance
- Environmental Challenges
  - Radiation
  - Thermal
  - Planetary Protection
  - Baseline mission duration
- Specific Energy as currency for design
- System Design
  - Energy as a consumable
  - New approach for contingency and margin management

Background & Relevance

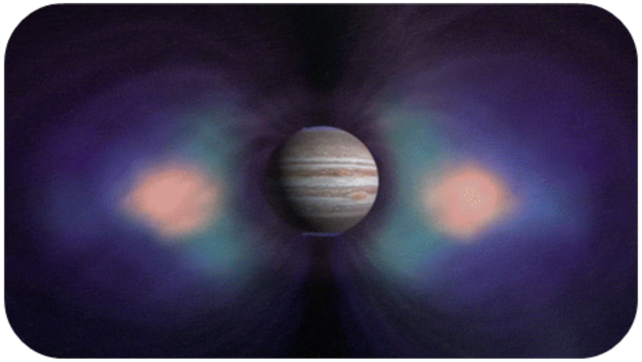
- JPL is studying a mission concept that would place a robotic lander on the surface of Europa, an icy moon of Jupiter
- Key goals include:
  - search for biosignatures
  - assess habitability
  - characterize the surface
- 20+ day surface mission

Artist's Concept

Environmental Challenges

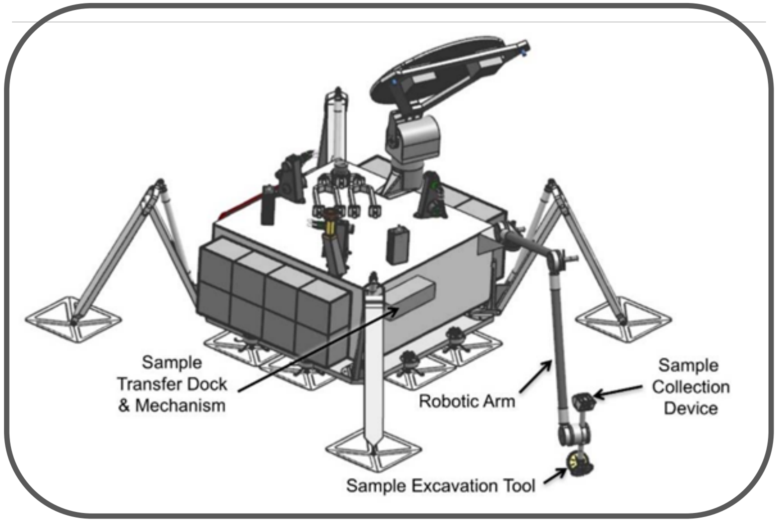
Radiation

- Total ionizing dose (TID) of ~1.7 Mrad behind 100 mil Al (Si equivalent)
- Drives 300 krad rated parts and material selection for battery cells and modules
- Reduces energy delivered at the surface
- Limits surface lifetime



Thermal

- Cost of survival on surface is high
- Opportunity to reclaim power system thermal dissipation to improve overall system efficiency

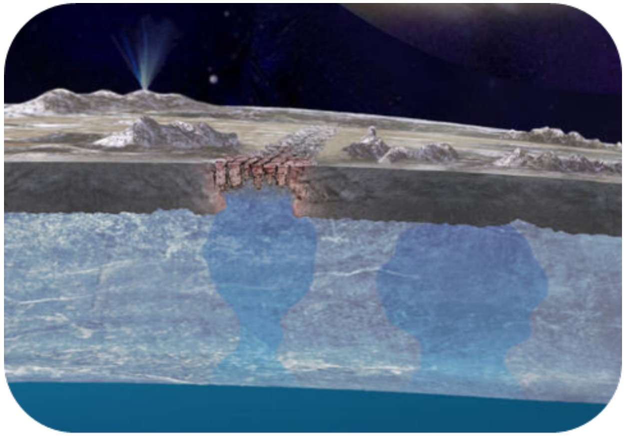


Artist's Concept

Environmental Challenges

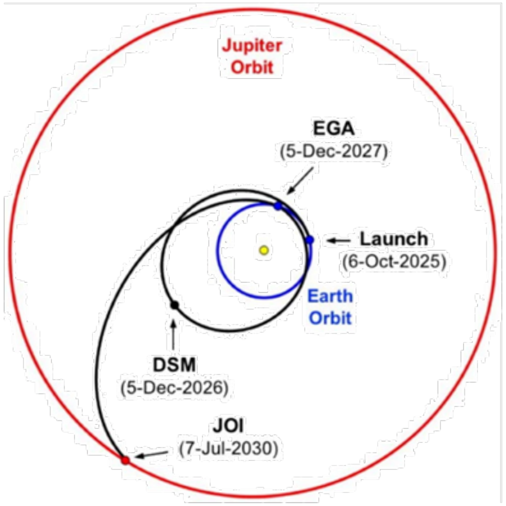
Planetary Protection (PP)

- Less than 10^{-4} probability of contaminating the Europan ocean by a viable Earth microorganism
- Sterilizing batteries impacts performance



Baseline Mission Duration

- 7 year cruise phase, plus assembly, integration, and test
- Low temperature storage planned to minimize degradation over time



Example trajectory from SDT Report

Specific Energy Drives Design

Mass Efficiency

- Each Lander kilogram is amplified many times by growth in descent, de-orbit, and cruise stages
- Mass is primary driving requirement

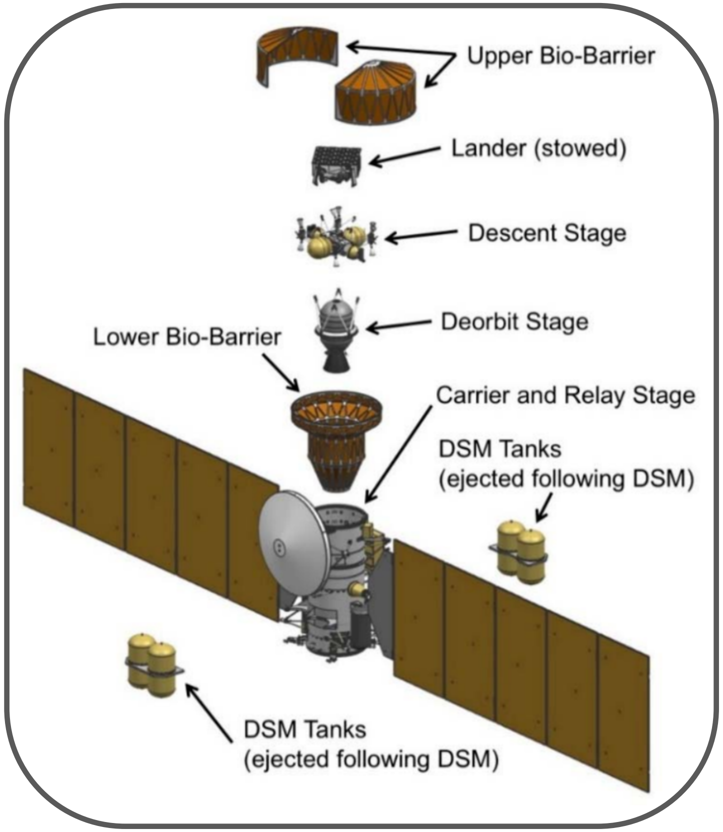
Power generation/energy storage trade:

X Radioisotope thermoelectric generator (RTG) scored low in mass, ease of integration, and right sizing power system life

X Solar power scored low in mass, volume, and pointing requirements

X Fuel cells scored lower than Li-CFx primary batteries for specific energy

✓ Li-CFx primary batteries scored high for energy density, heat generation, and benefitted from a mission concept that is inherently life limited by radiation

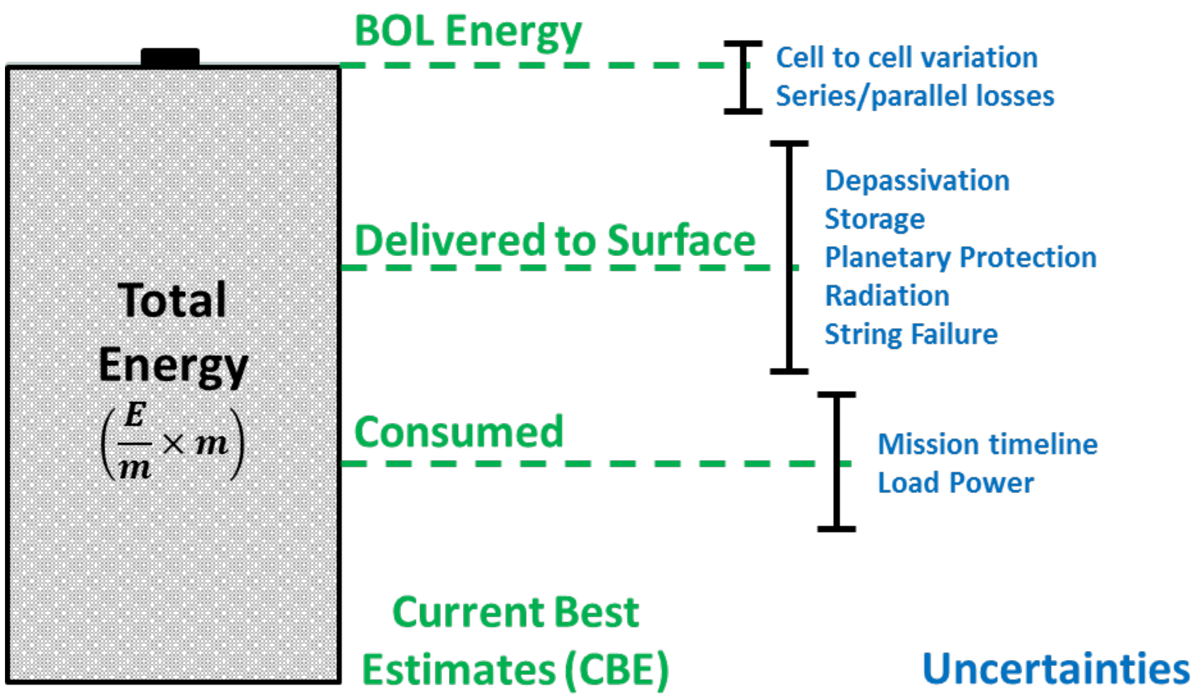


Baseline Flight System

With primary battery, energy = mass

Energy as a Consumable

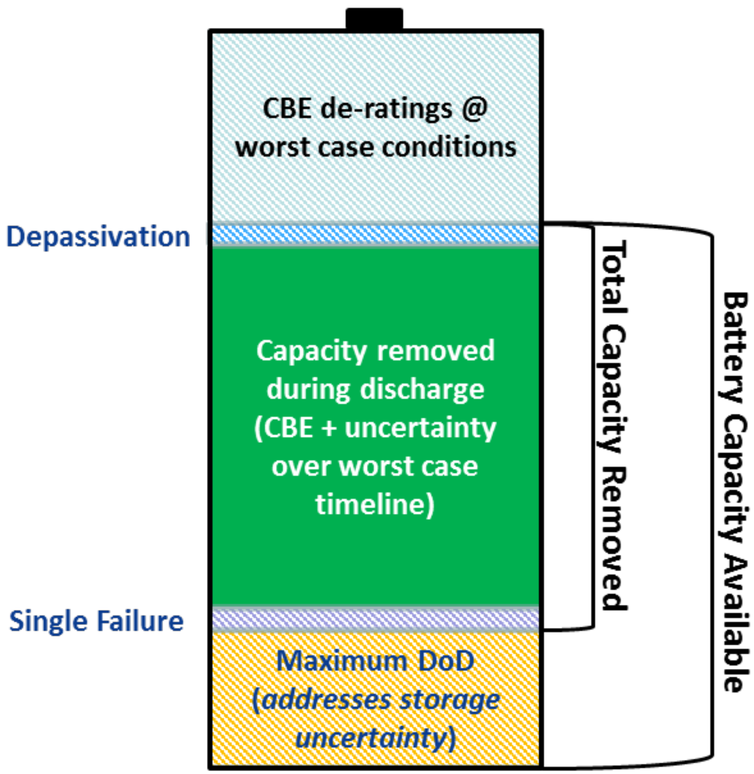
- Beginning of life (BOL) energy can be estimated based on available mass
- Estimates on energy delivered to the surface and energy consumed have error bars due to uncertainty



How can one ensure energy delivered > energy consumed?

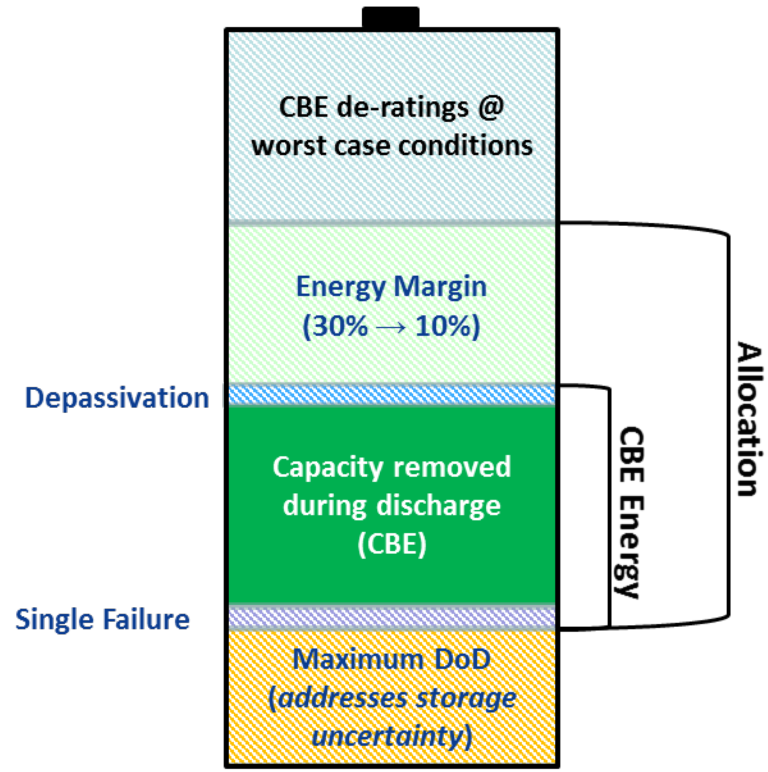
Traditional Approach to Battery Energy Sizing & Margin

Size Battery



$$\text{Max DoD} \geq \frac{\text{Total Capacity Removed}}{\text{Battery Capacity Available}}$$

Calculate Margin



$$\text{Margin} = \frac{\text{Allocation} - \text{CBE}}{\text{Allocation}}$$

Large, stacked margins result in unsupportable battery mass

Alternative Approach to Battery Energy Sizing & Margin

- Traditional approach stacks margins and sizes to worst case to cover uncertainties in energy consumption and storage
- Uncertainties, margins, de-ratings, and degradations can be combined in a statistically sound approach that is more mass efficient

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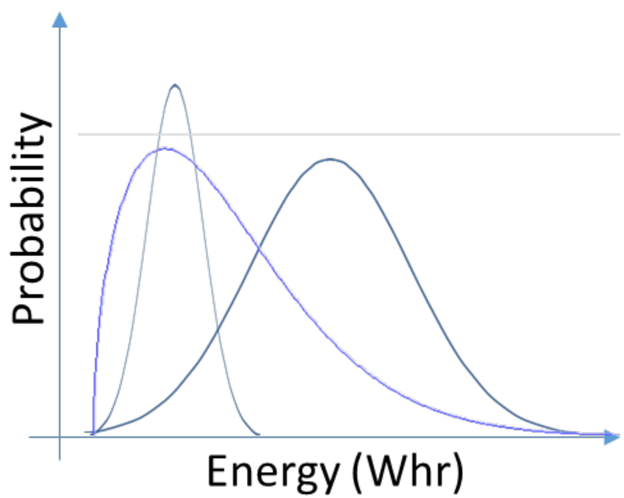

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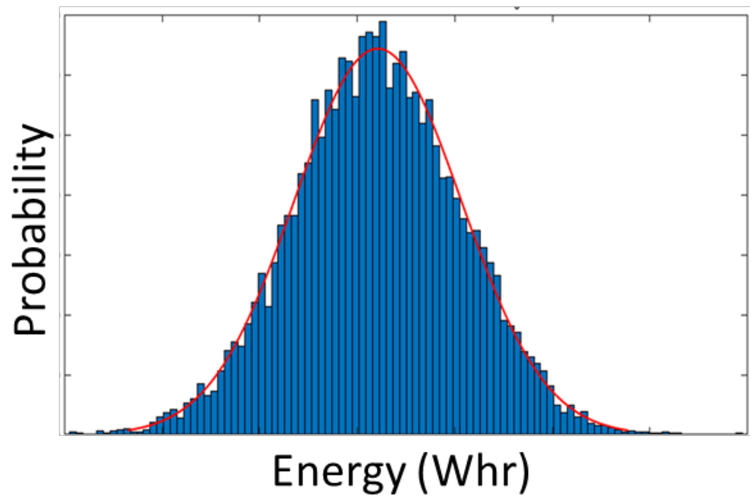


Single system margin added to 95% confidence consumption

Energy Consumers

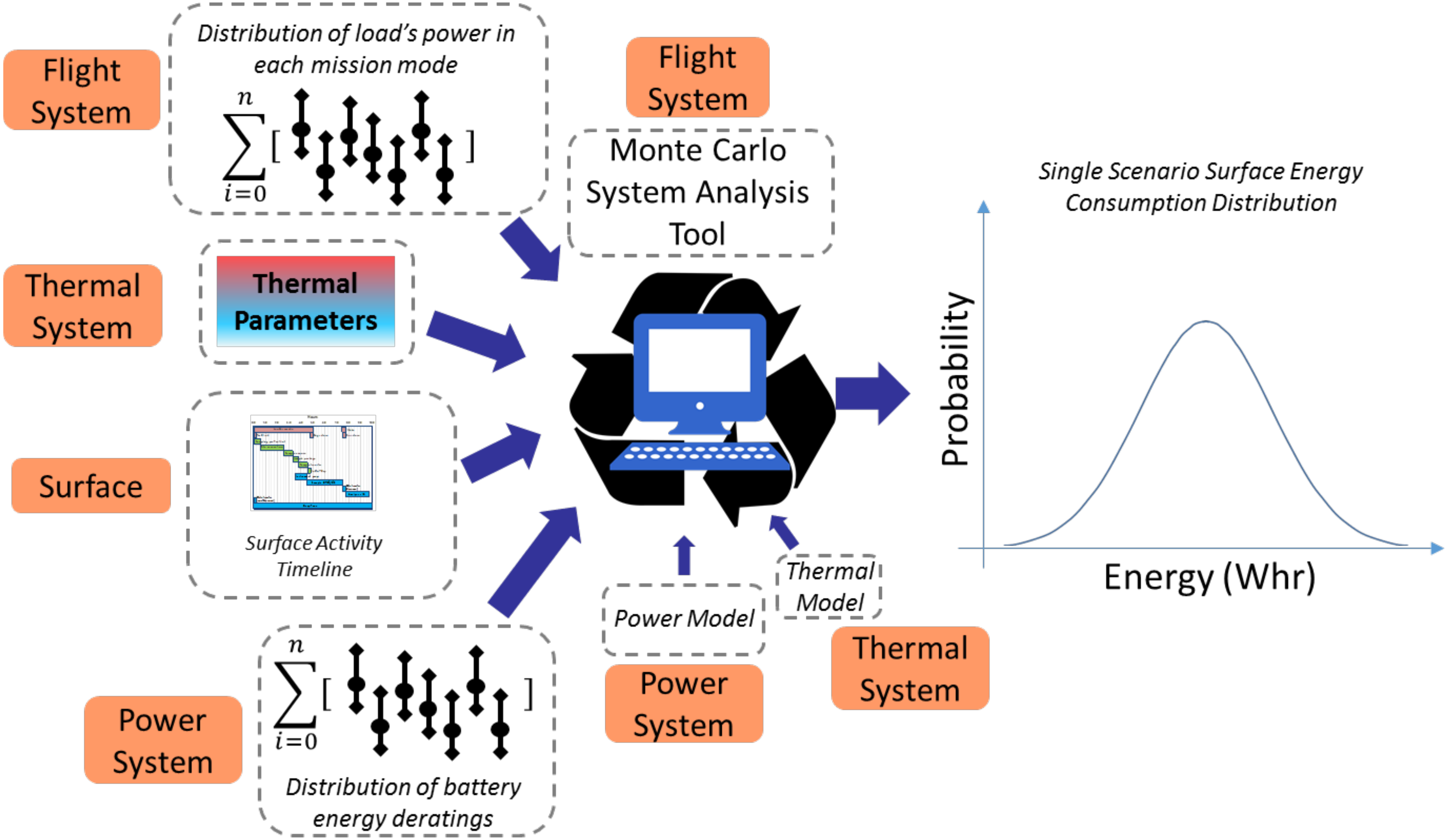
- Include degradations, losses, and loads:
  - Surface/mission activities
  - Duration on surface (cost of survival)
  - Depassivation Energy
  - Single Fault Tolerance (loss of strings)
  - Battery Integration Losses
  - Calendar Fade (time @ temperature)
  - Radiation Losses (PP + environmental)
  - Activity durations & mission timeline
  - Load power

Cell Test Facility

- Consumption distributions are based on test data, historical observation, and subject matter experts
- Distributions are updated through testing to reduce uncertainty

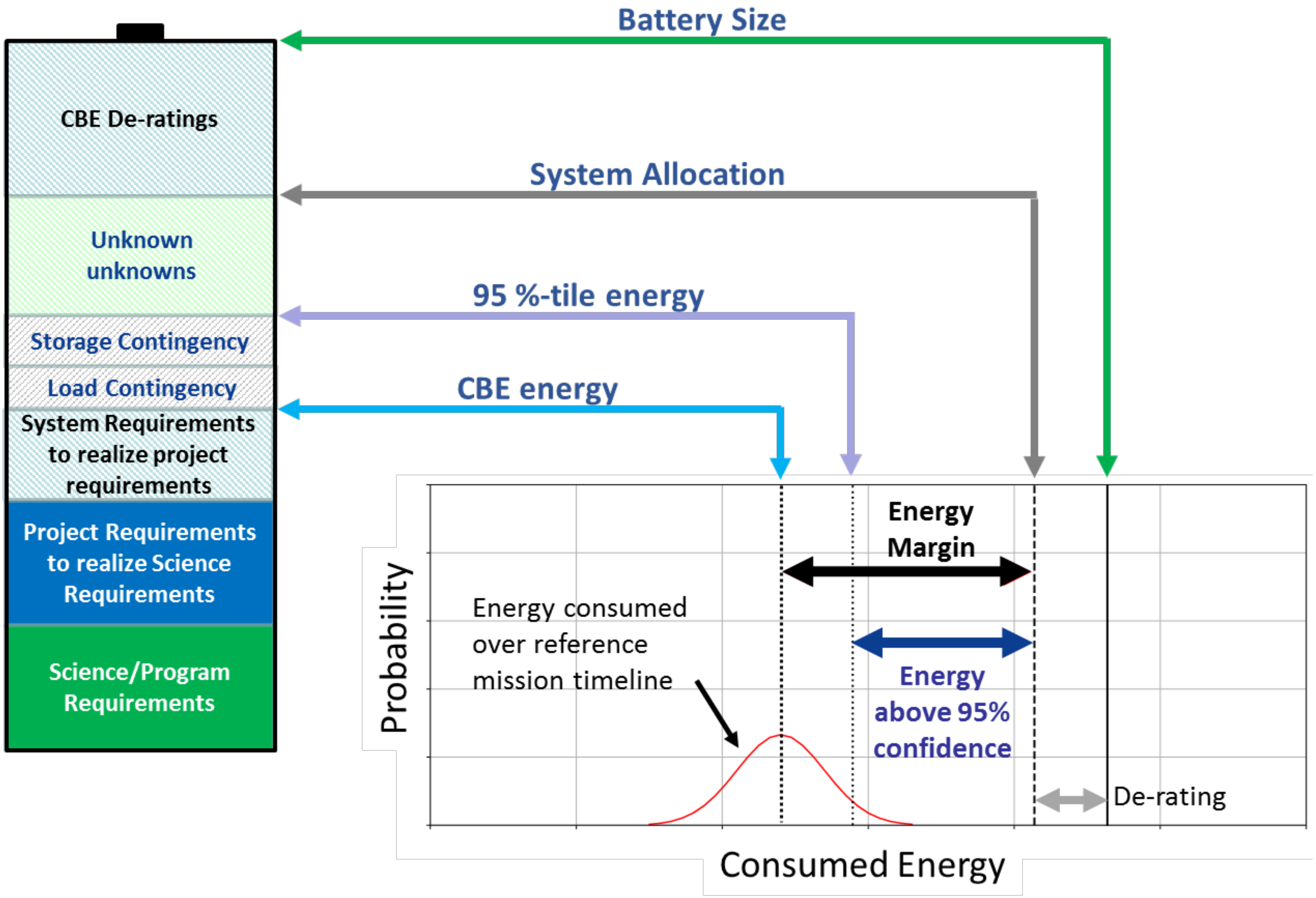
Extensive testing of each energy consumer required to benefit from statistical approach

Energy Consumption Calculation

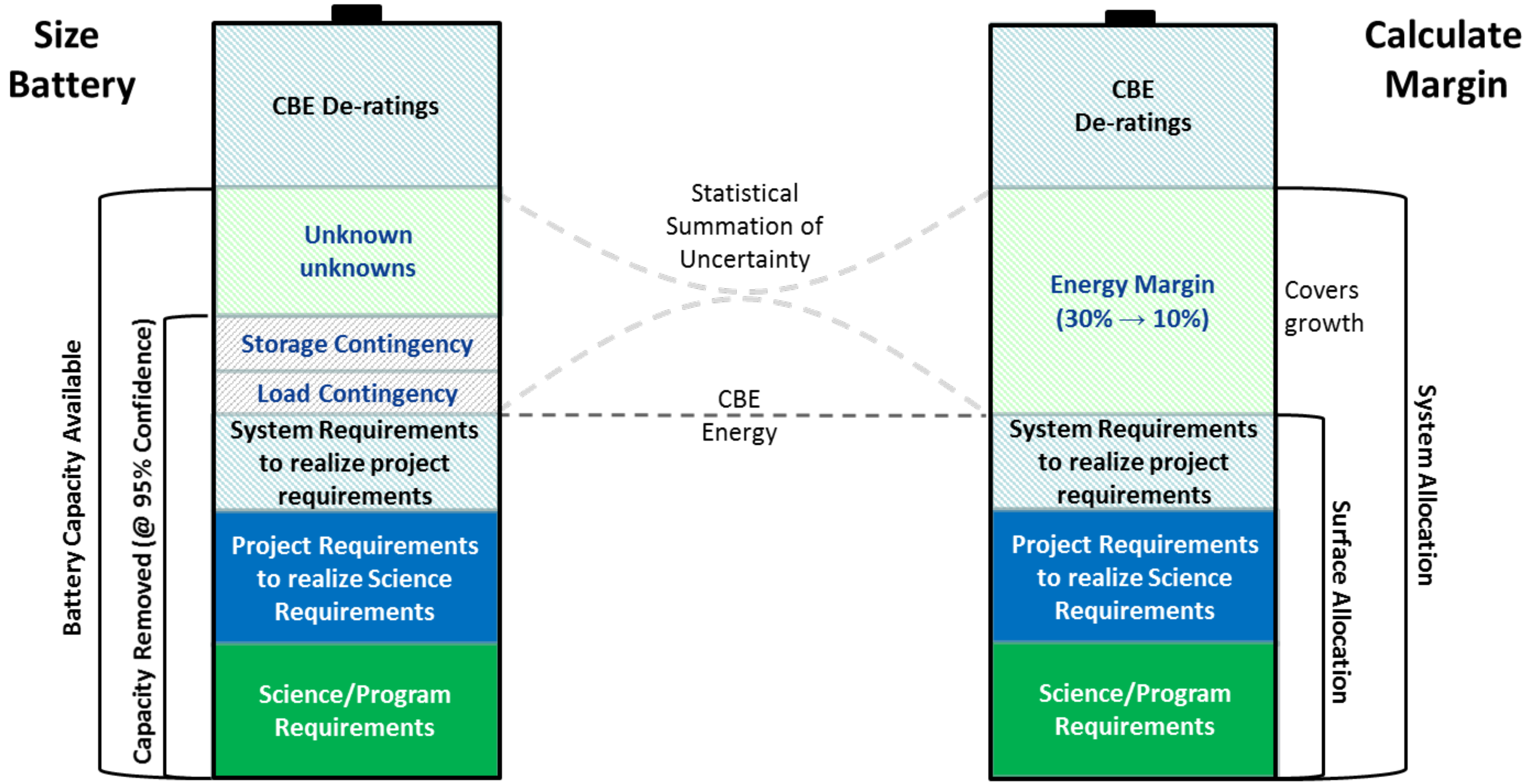


Analysis re-run for any new input

Statistical Stack-Up



Resultant Sizing Requirements



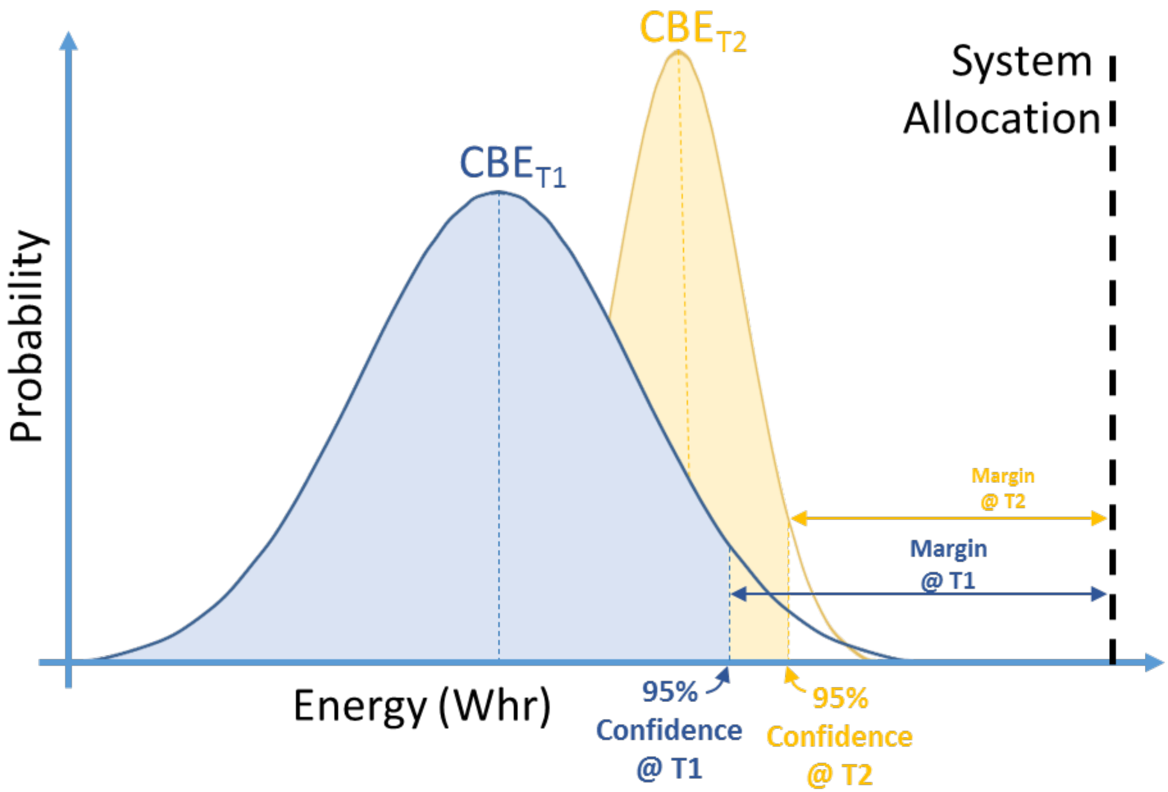
$$80\% \geq \frac{\text{Total Capacity Removed}}{\text{Battery Capacity Available}}$$

$$\text{Milestone Margin} \leq \frac{\text{System Allocation} - \text{Surface Allocation}}{\text{System Allocation}}$$

Both inequalities must be satisfied simultaneously

Energy Margin Burndown

- CBE likely to move to the right as time passes, but confidence also increases (with testing), decreasing the width of the distribution



Project Milestone	Required Margin
MCR	30%
SRR	30%
PDR	20%
CDR	15%
SIR	10%
Launch	10%

Margin burndown follows a traditional profile

Conclusions & Next Steps

Conclusions:

- Statistical approach to power system sizing is appropriate for primary battery based lander missions
- Traditional approach results in > 35% larger battery by mass (CBE)

Next Steps:

- Executing multiple rounds of testing on battery cells
  - Cell characterization (rate, temperature, etc.)
  - Characterizing radiation effects
  - Pursuing material selections
  - Storage testing
  - Safety and fault propagation testing
- Continue to mature design of experiments based on results
- Track increasing maturity of loads

Acknowledgement & References

Acknowledgement:

- This research was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology under a contract with the National Aeronautics and Space Administration and supported by JPL's Europa Lander project.

References:

- Europa Lander Study 2016 Report: Europa Lander Mission. JPL D-97667

https://europa.nasa.gov/resources/58/europa-lander-study-2016-report/